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USE OF RIBLETS TO OBTAIN DRAG REDUCTION ON AIRFOILS AT HIGH REYNOLDS NUMBER FLOWS

by
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National Aeronautical Establishment

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USE OF RIBLETS TO OBTAIN DRAG REDUCTION ON AIRFOILS AT HIGH REYNOLDS NUMBER FLOWS

UTILISATION DE PETITES NERVURES POUR OBTENIR UNE DIMINUTION DE LA TRAÎNÉE SUR DES PLANS PORTEURS SOUMIS À DES VITESSES CORRESPONDANT À DES NOMBRES DE REYNOLDS ÉLEVÉS

by/par

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SUMMARY

An investigation was carried out to study the drag reduction capabilities of riblets (commercially available) when installed on a supercritical airfoil which was aerodynamically tested in the NAE's High Reynolds Number 2 D Test Facility. The flow conditions in this test ranged from M = 0.15 to M = 0.76, and Re/ft = 1.5 $\times 10^6$ to Re/ft = 8 $\times 10^6$. The airfoil with riblets exhibited less drag than a completely turbulent airfoil (without riblets) for Mach Number M $\leqslant$ 0.5 and Reynolds Numbers Re/ft $\leqslant$ 5 $\times 10^6$. It was found that the thinner riblet material (0.0013) gave more attractive drag results than the thicker riblet (0.0030). However, at higher Mach numbers and Reynolds number no drag reduction was observed.

RÉSUMÉ

Une étude a été menée afin de déterminer la capacité de réduction de la trainée de petites nervures (disponibles dans le commerce) installées sur un plan porteur supercritique qui a été éprouvé aérodynamiquement dans la soufflerie de l'ÉNA pour les essais bidimensionnels à nombres de Reynolds élevés. Les vitesses utilisées pour l'essai variaient entre 0.15 et 0.6 M et entre 1.5 $\times 10^6$ et 8 $\times 10^6$ Re/pi. Le plan porteur muni de petites nervures a présenté moins de trainée qu'un plan porteur complètement turbulent (sans petites nervures) pour un nombre de Mach égal ou inférieur à 0.5 et pour un nombre de Reynolds égal ou inférieur à 5 $\times 10^6$ Re/pi. Les nervures plus minces (0.0013) ont donné de meilleurs résultats que les plus épaisses (0.0030). Toutefois, on n'a observé aucune diminution de la traînée à des nombres de Mach et de Reynolds plus élevés.

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NOMENCLATURE

α	corrected airfoil incidence
C_L	lift coefficient
C_{LB}	lift coefficient as measured by the balance
C_f	local skin friction coefficient
C_{DW}	average drag coefficient from probes 1 , 2 and 3.
C_M	pitching moment about the 1/4 chord
M	Mach Number
s	spacing distance between riblet grooves
h	height of grooves on riblets
s^+	riblet scaling parameter as defined in equation 1
h^+	$h^+ = (hU_\infty/\nu_\infty)\sqrt{(C_f/2)}$
Re/ft	Reynolds Number based on 1 foot length
U_∞	free stream velocity
v/U_∞	suction value , ratio of velocity normal to sidewall to free stream velocity
ν_∞	kinematic coefficient of viscosity

USE OF RIBLETS TO OBTAIN DRAG REDUCTION ON AIRFOILS AT HIGH REYNOLDS NUMBER FLOWS

INTRODUCTION

This paper reports some results from an investigation concerning the application of riblets on airfoil surfaces at a range of Mach Numbers from M=0.15 to 0.76 and up to a Reynolds Number of $8X10^6$ per foot. The measurements were made in NAE's 15"X60", 2 D High Reynolds Number Trisonic Facility. Two sizes of riblet sheets having groove measurements of 0.0013 and 0.0030 inches were mounted on a 13% thick airfoil. The effective drag on the airfoil, with and without the riblets was measured by a sidewall -mounted traversing rake supporting four pitot probes.

The first part of this report provides a little background to this work followed by a brief description of the facility and the experiment. Results obtained from the study are then analysed and discussed.

1. BACKGROUND

Riblets have been successfully tested on flat plate surfaces at low Reynolds and Mach Numbers [1] and [2]. Squire and Savill reported some interesting local skin friction C_f measurements and one set of overall drag data [3] on ribletted flat surfaces at M=0.88 and Reynolds Number up to $6.7X10^6$ per foot. It was found that maximum skin friction reduction (10%) is achieved when the riblet dimension in wall units is of the

order of $h^+=40$. For maximum overall drag reduction (4%) the riblet size is of the order of $h^+ =20$. Mclean et al [4], at Boeing tested the same riblets as the ones used in the present investigation on the wing of a T-33 aircraft, and measured the local drag effects through a range of Mach Numbers (M=0.35 to 0.7)and Reynolds Numbers (up to $4.43X10^6$ per foot) flight conditions. They found that an average of about 6 % skin friction reduction was possible for an s^+ range of about 6 to 25.

The present investigation is along similar lines to the above work, with the exception that here more emphasis is placed on the total drag measurements rather than the local skin friction measurement. The flow conditions in the present investigation were also similar to the ones in the tests described in References 3 and 4. The total effective drag, C_{DW}, measured on a riblet -mounted airfoil here, as well as the available high Reynolds Number drag data (which is very scarce) in literature should be very useful in assessing the overall feasibility of these devices as passive means of obtaining meaningful drag reduction on aircraft surfaces.

2. TEST FACILITY

Figure 1 shows the schematic of the 2 D insert (15"X60") which is mounted in the 5 ft X 5 ft test section of the NAE trisonic wind tunnel. The airfoil was installed for testing in the insert as shown. Reference 5 contains a detailed

description of the NAE's High Reynolds Number 2 D Facility used in the present investigation.

The floor and ceiling of the test section are perforated with a porosity value of 20.5%. Wall interference effects are accounted for by applying Mokry's [6] correction routines. This entails taking measurements of static wall pressures both at floor and at the ceiling. The model on which the riblets were installed was supported on two, 3-component sidewall balances which rotate with the model. Both north and south sides react to produce the axial and normal loads as well as the resultant moment.

The boundary layer close to the model was controlled by suction through the porous surface on the sidewall to provide a good 2 D flow. A suction box at each end of the airfoil (shown in Figure 1) was used to maintain a v/U_∞ value of about 0.0084 to 0.01.

The wake drag was determined by measuring the momentum defect in the far wake using the standard sidewall mounted traversing wake rake with four pitot probes. The setup is shown in Figure 2. The signal from probe 4 is often ignored as it is sometimes affected by the disturbed sidewall boundary layer. The total effective drag C_{DW} for this test is computed from an average of the remaining three probes.

3. THE EXPERIMENT

A 13% thick supercritical model designated as NAE-76-060-13:1 was used as the reference airfoil in this investigation. The design conditions for this model are $C_L = 0.6$ at $M = 0.76$ and a chord Reynolds number of $Re/c = 15X10^6$.

Riblets having the groove height h equal to the spacing width s (h=s) were tested in this experiment. Their sizes were s = 0.0030 and 0.0013 inches. Based on the relationship:

$$s^+ = (sU_\infty/\nu_\infty)\sqrt{(C_f/2)}, \qquad ---(1)$$

these two sizes for s correspond to the optimum value of $s^+ \simeq 15$, at Reynolds Numbers of 1.4 Million and 3.5 Million respectively for flat plate type geometries. Beyond this optimum value of s^+ (for increasing Reynolds Number) as reported in Reference [2], there is a rapid deterioration in riblet performance.

The airfoil was first tested with a transition strip to obtain baseline data at all the flow conditions. The grit size for each flow condition was appropriately calculated following the procedure in Reference [7]. The transition strip was located at 7 % of chord from the leading edge (LE) on the upper surface , and 15 % of chord from the LE on the lower surface. It was reasoned that the results obtained from an airfoil supporting a turbulent boundary layer would form a

good basis of comparison with the results obtained from the riblet installed data. From application point of view it also seems more practical to verify the riblet performance against this type of a turbulent environment for which they are typically designed.

The preceding runs were then repeated using an airfoil with riblets installed (airfoil+riblet).Both 0.0030 inch and 0.0013 inch riblet sheets were used in this series of experiment. The riblet grooves were aligned with the flow. Every effort was made to achieve a perfect contact when installing the self adhesive riblet sheets on to the model surface.

4. DISCUSSION OF RESULTS

Figure 3 shows the wake drag C_{DW} plotted against the lift coefficient C_{LB} (obtained from the balance measurement) for the three configurations of the airfoil under investigation at a Mach Number of 0.15 and Re/ft $=1.6X10^6$. Through the C_{LB} range shown , the 0.0013 riblet drag data are about 0.0040 to 0.0050 in drag value (C_{DW}) better than the corresponding transition fixed (TF) airfoil drag data. The 0.0030 inch riblet also gives a drag reduction in some cases as much as 0.0040 in drag value less than the drag obtained from TF conditions. The C_{LB} versus α graph for these conditions shown in Figure 4 indicates that the lift is not too drastically affected by the application of riblets. The

pitching moment C_M on the other hand plotted against C_{LB} in Figure 5, seems to be fairly sensitive to these riblets in the range $0.0 \geq C_{LB} \geq 0.5$. At these low Mach number and Reynolds number conditions the riblets seem to have a stabilizing effect upon the pitching moment.

Figure 6 shows the similar drag data at a higher Mach Number of M=0.3 and Reynolds Number $Re/ft=3.0X10^6$. Again, the airfoil with the 0.0013 inch riblets installed outperforms the TF airfoil by at least 0.0040 in drag value at some C_{LB} conditions. It may be mentioned in passing that the high Reynolds number facility in which these tests were conducted is not highly suited for such low Reynolds Number flows as the above two cases. Hence for some high C_{LB} values , data showing unexplained fluctuations in drag had to be discarded. The pitching moment C_M relationship with C_{LB} for this case is shown in Figure 7. The thinner 0.0013 inch riblet, consistent with its drag performance has a stabilizing effect upon the pitching moment. The thicker 0.0030 inch riblet gives more drag as well as poorer pitching moment response when compared to the other two configurations.

As the Mach Number is increased to M = 0.5 and Reynolds Number to $Re/ft=5X10^6$, the gains from riblets as seen in Figure 8, become less attractive. While the thicker 0.0030 inch riblet data is quite visibly worse than the turbulent TF airfoil, the thinner 0.0013 inch riblet still appears to show,

in some cases, about 5 drag counts advantage over the reference data.

Figures 9 and 10 show the riblet performance at still higher Mach and Reynolds numbers. In both cases it is quite clear that ribletted airfoil's performance dragwise is well below that of a turbulent airfoil. In both of these figures the 'clean wing', airfoil alone data is introduced only to provide another baseline for comparison of the data. As expected, the data for the transition fixed case shown in Figure 10, at a higher Reynolds Number, $Re/ft = 15X10^6$, shows less drag than the corresponding lower Reynolds Number data at $Re/ft = 8X10^6$.

The drag data obtained for all the above cases at C_{LB} = 0.25 and 0.5 , was also plotted against the parameter s^+ in Figure 11. As for the low Reynolds Number drag data for flat plate riblet models [2] , the total drag on airfoils equipped with riblets also increases rapidly with the increase in s^+. The plot shows that these two riblets configurations are useful, at least up to an s^+ value of about 30. The trend in the data shows that both riblets performed satisfactorily around the optimum design value of $s^+ = 15$. The plot further indicates that continued drag reduction may be available below the minimum s^+ value (~ 7.21) tested in the current experiment, provided that thinner riblets could be manufactured or alternatively, the flow Reynolds Number be decreased.

The graph in Figure 11 essentially represents a global trend relationship between the riblet drag and the scaling parameter s+. A more rigorous study should bring out the individual effects of Mach Number and Reynolds Number upon the overall drag reduction effect of riblets .

5. CONCLUSION

The effect on drag by the application of riblets to a 13 % thick supercritical airfoil has been investigated in the NAE High Reynolds Number 2 D facility.

Wake drag measurements show that thinner riblets (0.0013) seem to work better than the thicker (0.0030) riblets.

At low Reynolds Numbers ($1.5X10^6$ to $3.0X10^6$) , drag reduction of the order of 30 % to 45 % drag may achieved by the application of the riblets. At a higher Reynolds Number, Re/ft = $5X10^6$ only the thinner of the two riblets (0.0013) seems to perform, in terms of drag reduction, better than the turbulent airfoil.

Measurements show that at higher flow Reynolds and Mach Numbers the riblets tend to increase the total drag on an airfoil.

Consistent with the drag measurements in literature [2], [3] and [4] , the total drag measurements for the riblet surfaced airfoils also show a sharp increase in drag with the increase of the Reynolds Number or the increase in s^+. Present results indicate that to obtain any reduction in drag the value of s+ must be less than 30.

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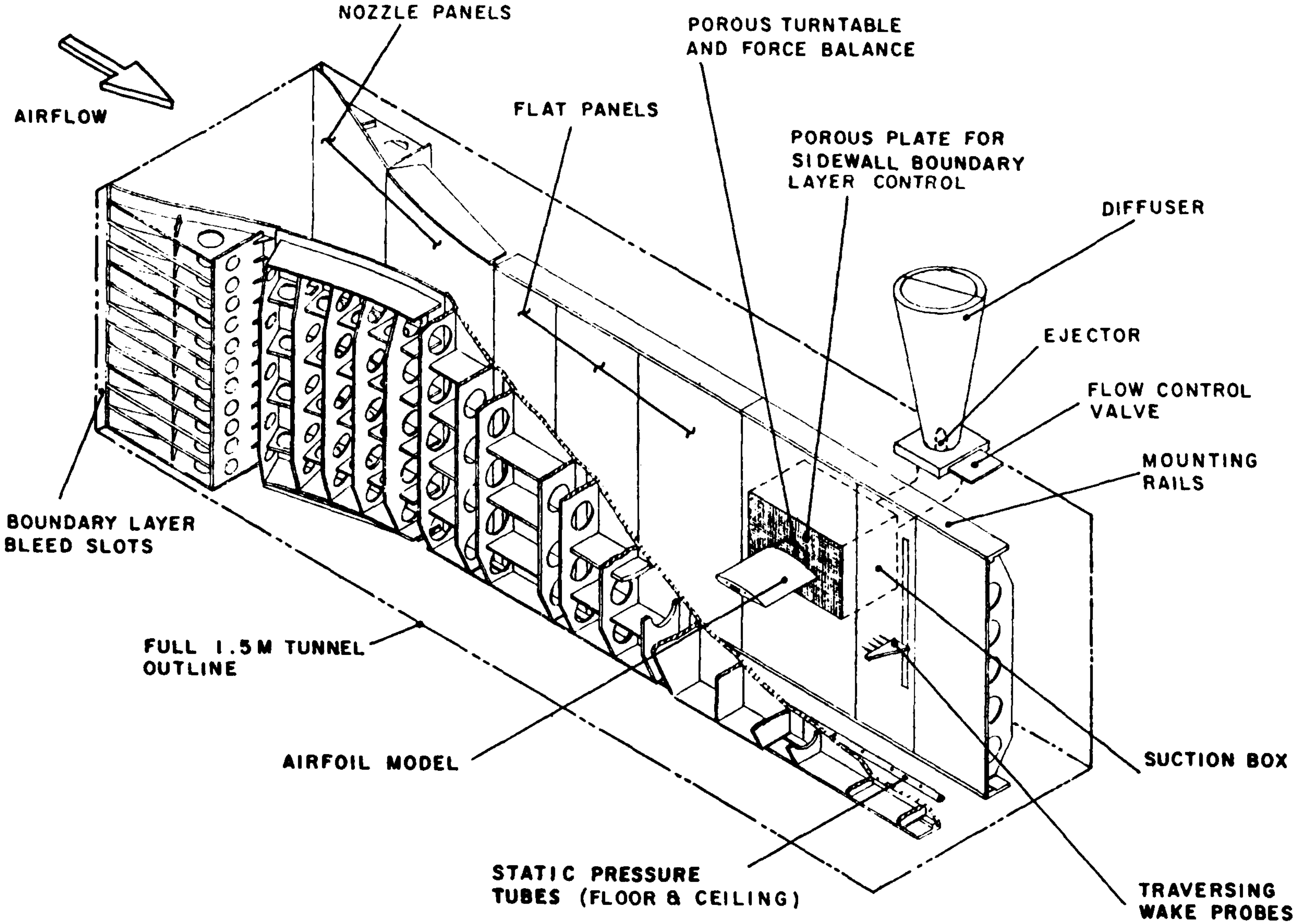

FIG. 1: NAE 2-DIMENSIONAL TEST SECTION

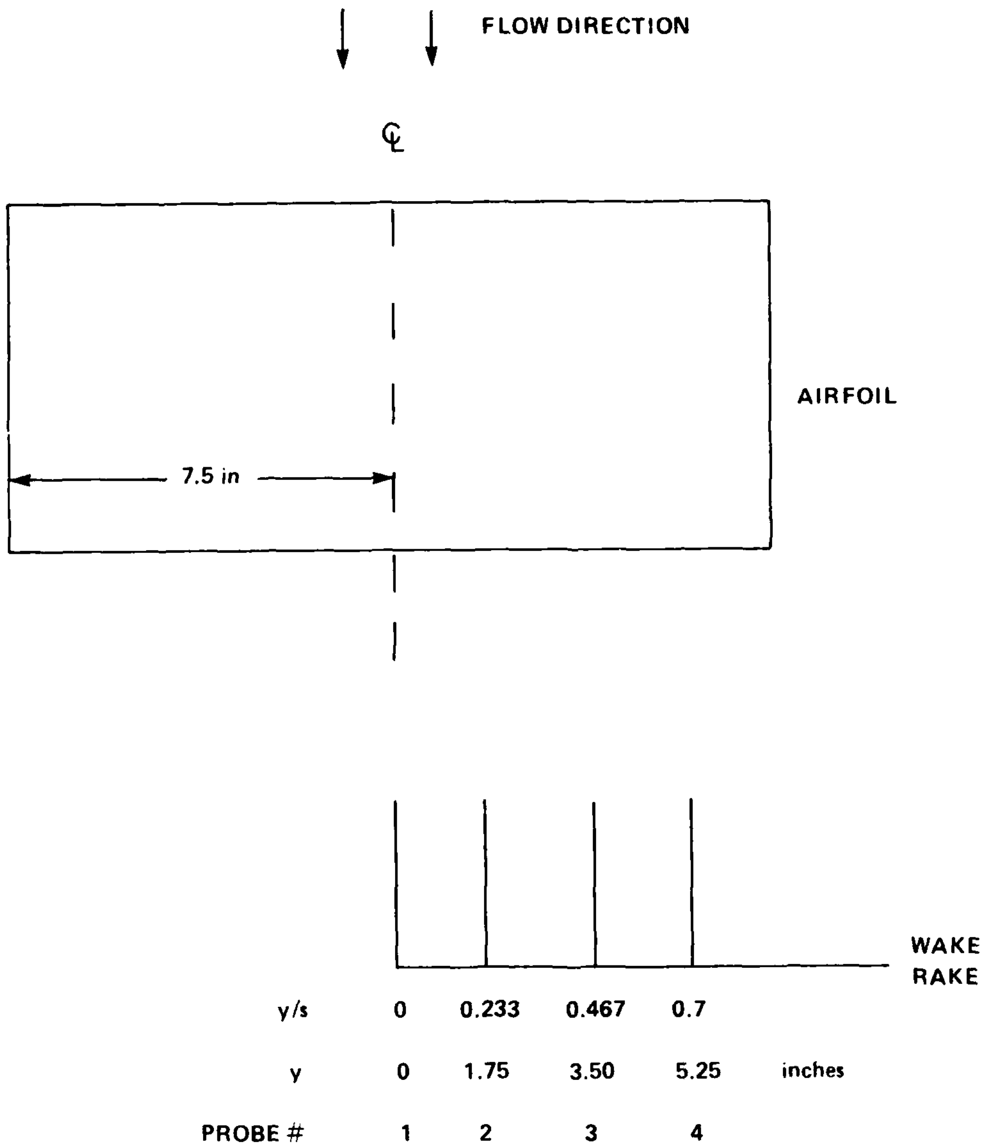

FIG. 2: THE WAKE RAKE PROBE LOCATIONS RELATIVE TO THE AIRFOIL

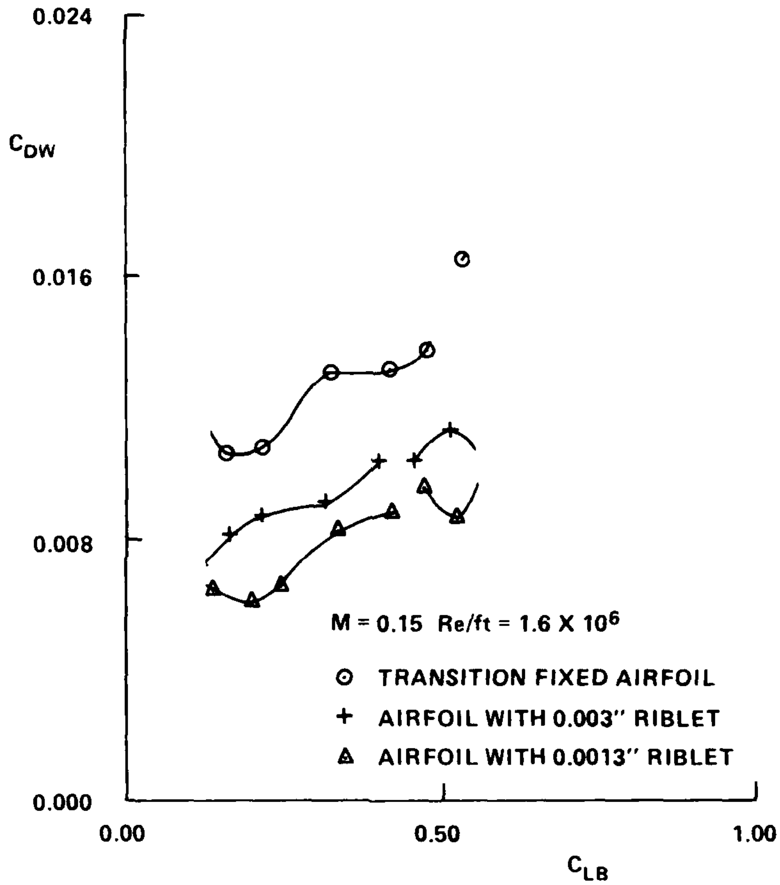

FIG. 3: WAKE DRAG C_{DW} PLOTTED AGAINST LIFT COEFFICIENT C_{LB}

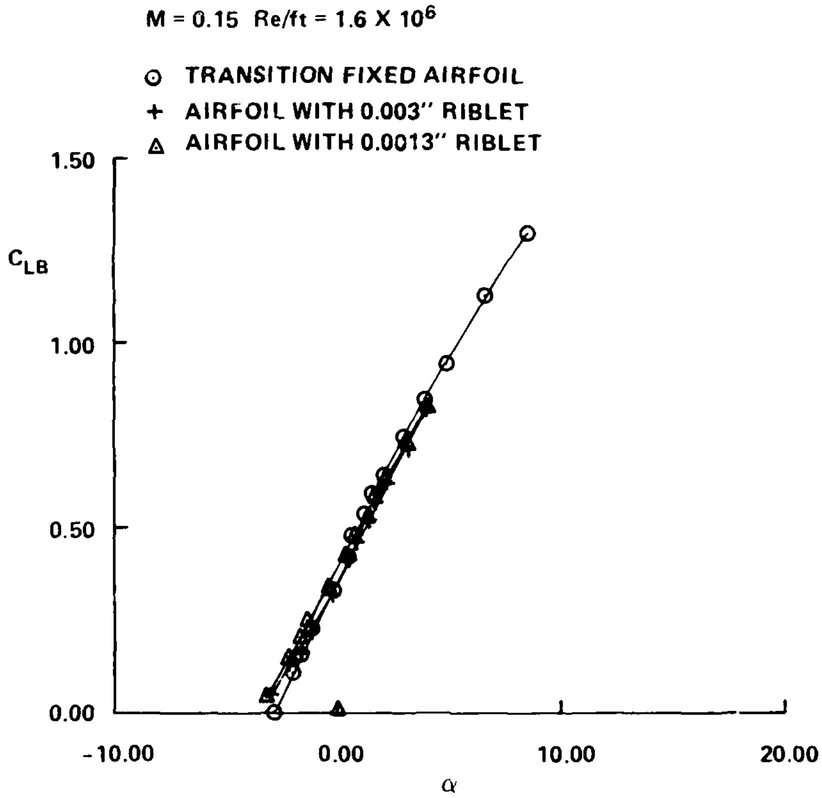

FIG. 4: COEFFICIENT OF LIFT C_{LB} VERSUS INCIDENCE α

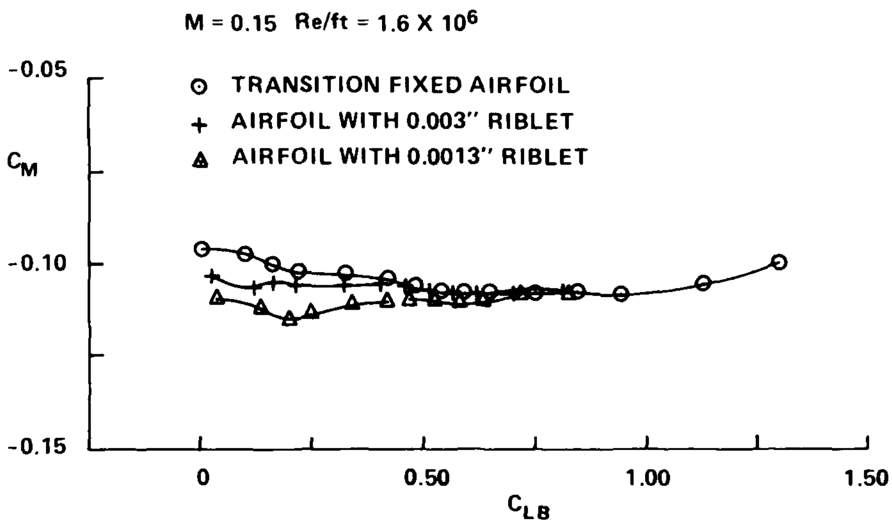

FIG. 5: PITCHING MOMENT C_M VERSUS COEFFICIENT OF LIFT C_{LB}

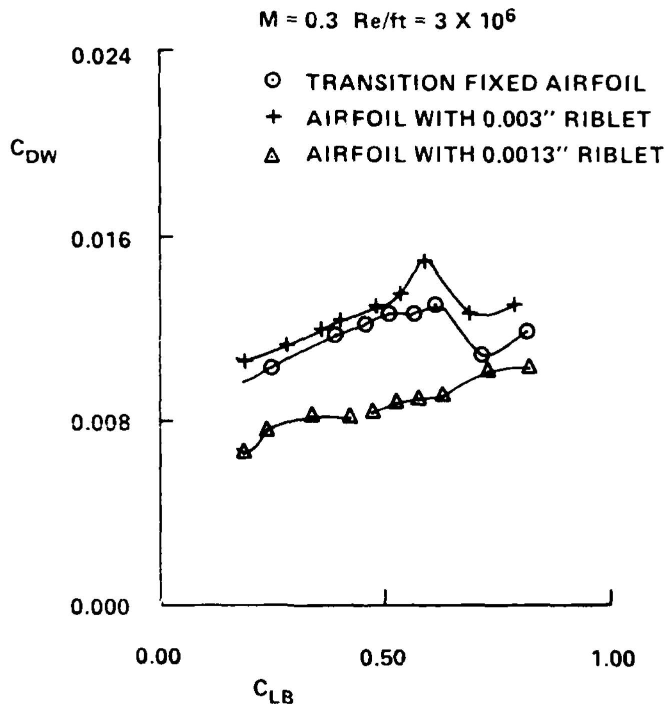

FIG. 6: WAKE DRAG C_{DW} PLOTTED AGAINST LIFT COEFFICIENT C_{LB}

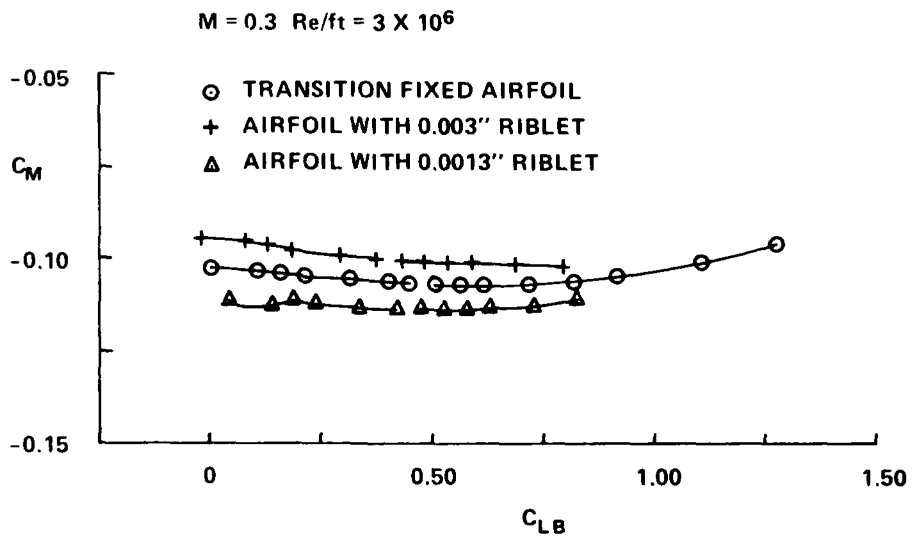

FIG. 7: PITCHING MOMENT C_M VERSUS COEFFICIENT OF LIFT C_{LB}

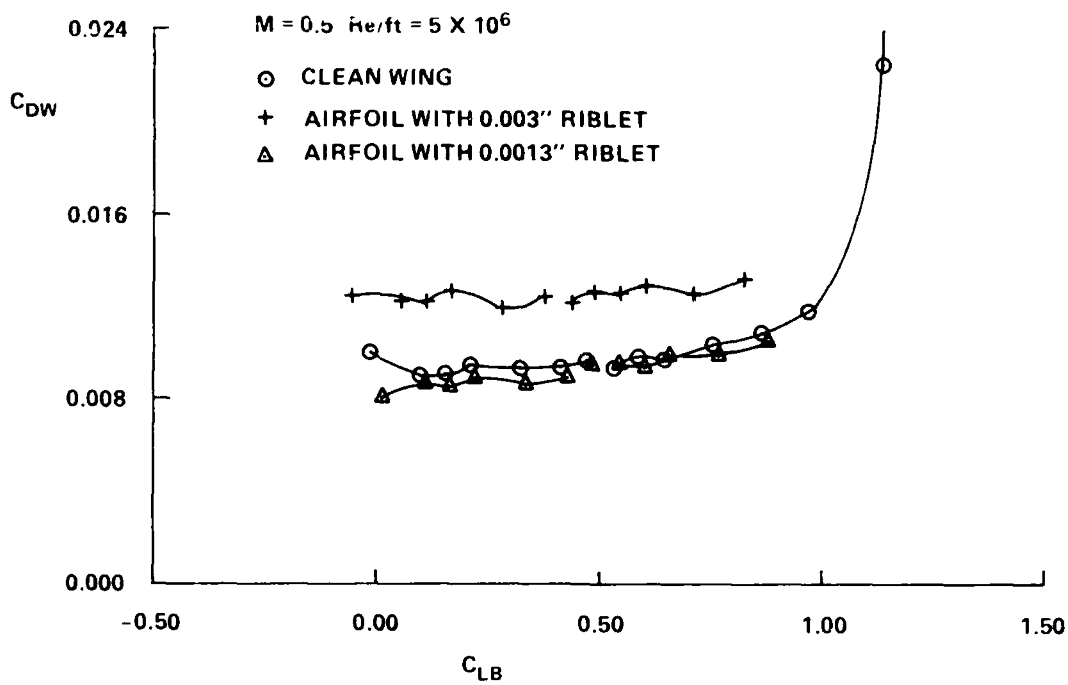

FIG. 8: WAKE DRAG C_{DW} PLOTTED AGAINST LIFT COEFFICIENT C_{LB}

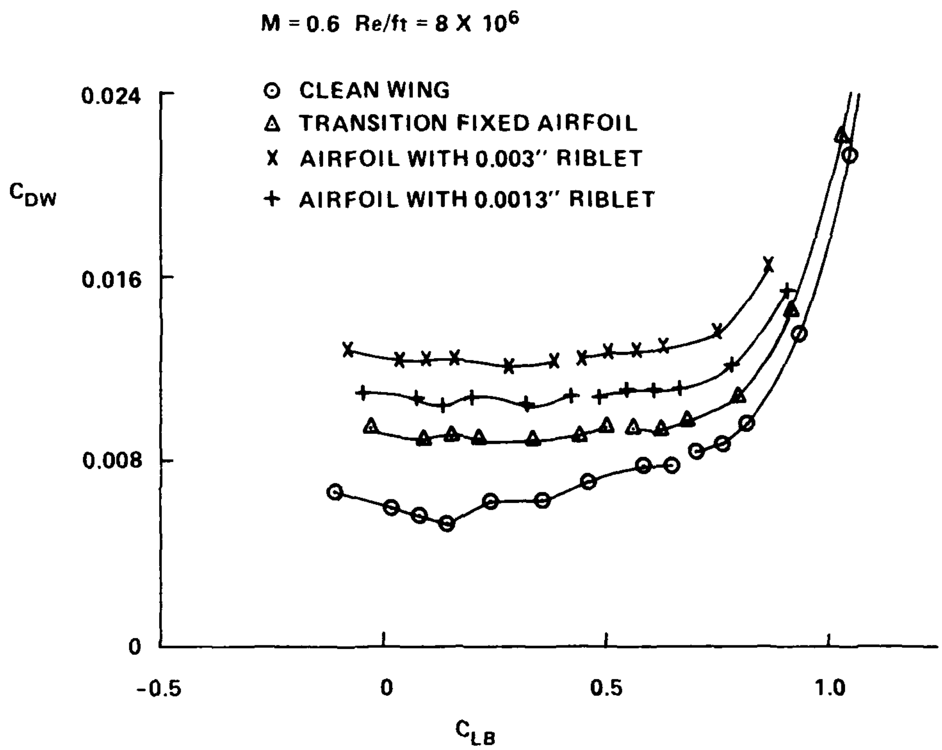

FIG. 9: WAKE DRAG C_{DW} PLOTTED AGAINST LIFT COEFFICIENT C_{LB}

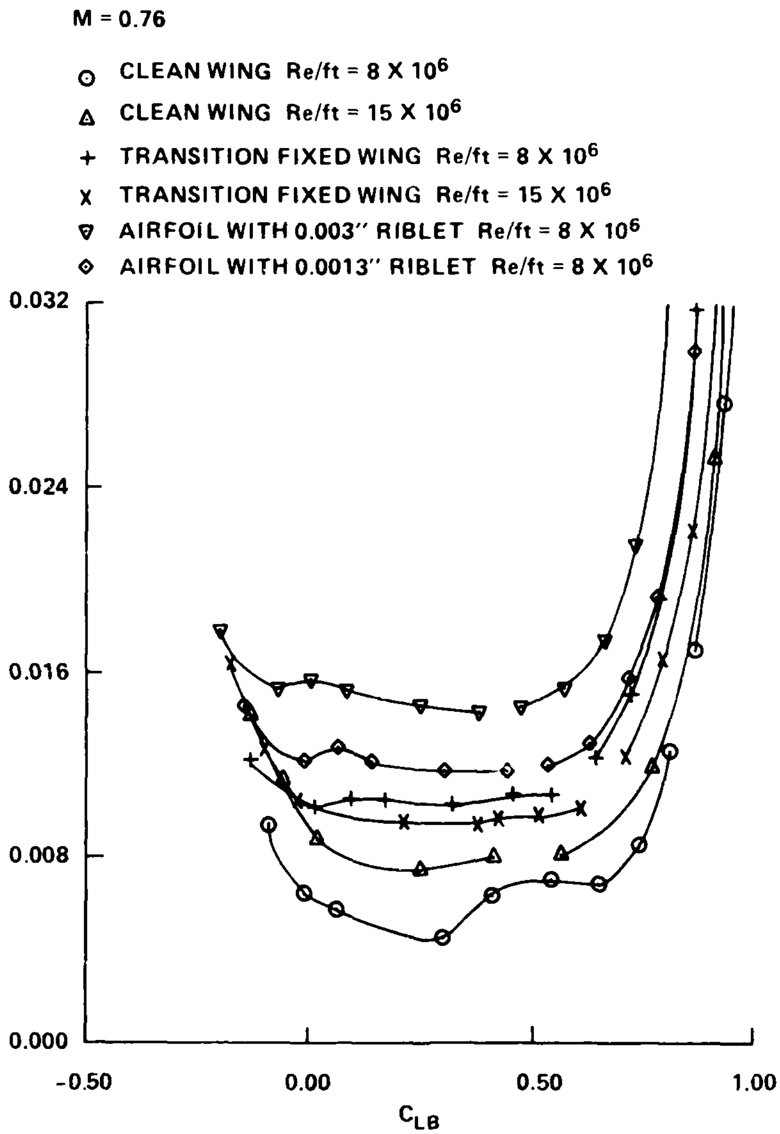

FIG. 10: WAKE DRAG C_{DW} PLOTTED AGAINST LIFT COEFFICIENT C_{LB}

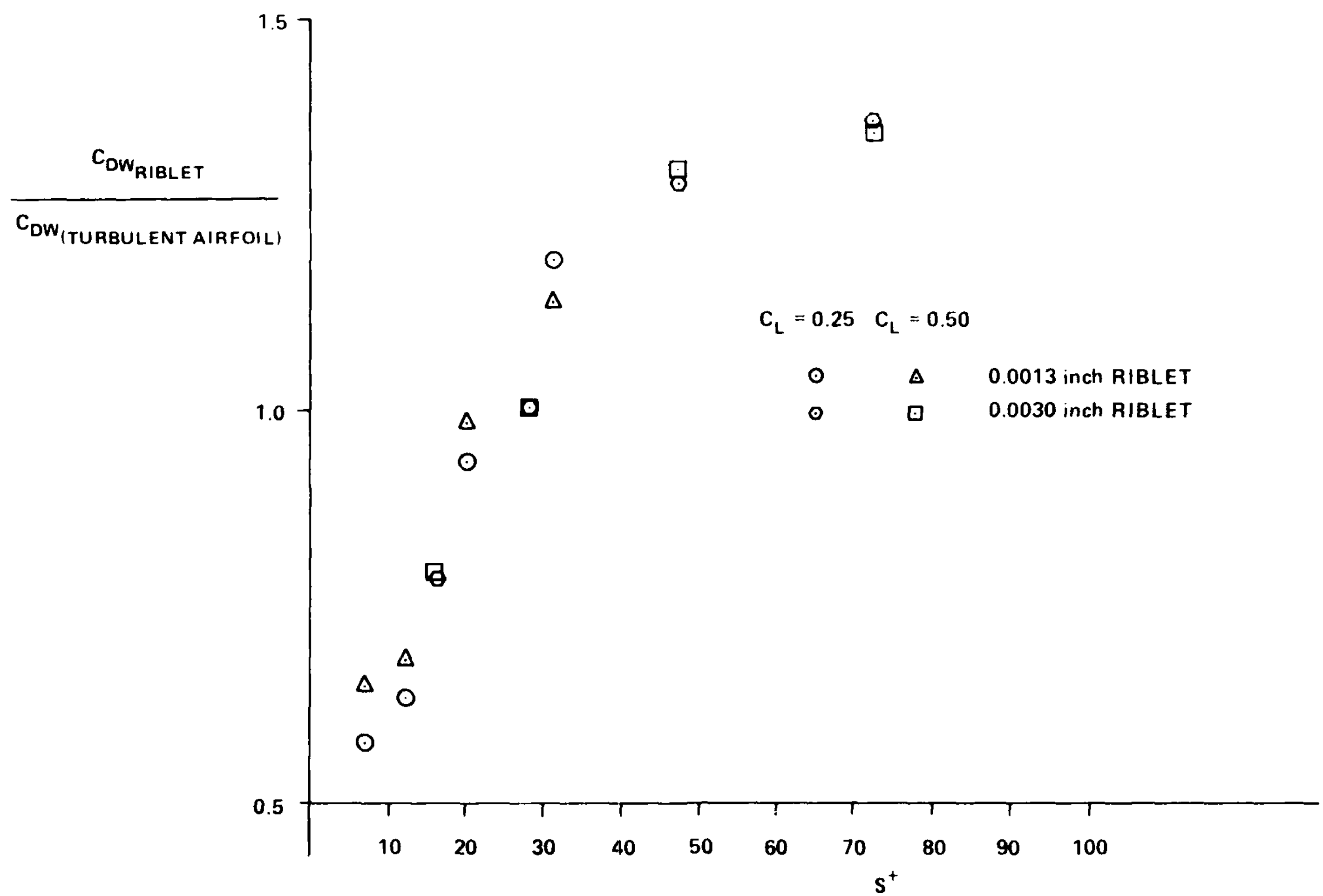

FIG. 11: DRAG OF AN AIRFOIL WITH RIBLETS RATIOED WITH RESPECT TO THE SAME TRANSITION FIXED AIRFOIL DRAG, VERSUS THE PARAMETER S^+

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DESCRIPTORS (KEY WORDS)/MOTS-CLÉS

1. Drag reduction
2. Airfoils — drag reduction
3. Reynolds numbers

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SUMMARY/SOMMAIRE

An investigation was carried out to study the drag reduction capabilities of riblets (commercially available) when installed on a supercritical airfoil which was aerodynamically tested in the NAE's High Reynolds Number 2 D Test Facility. The flow conditions in this test ranged from $M = 0.15$ to $M = 0.76$, and $Re/ft = 1.5 \times 10^6$ to $Re/ft = 8 \times 10^6$. The airfoil with riblets exhibited less drag than a completely turbulent airfoil (without riblets) for Mach Number $M \leqslant 0.5$ and Reynolds Numbers $Re/ft \leqslant 5 \times 10^6$. It was found that the thinner riblet material (0.0013) gave more attractive drag results than the thicker riblet (0.0030). However, at higher Mach numbers and Reynolds number no drag reduction was observed.

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